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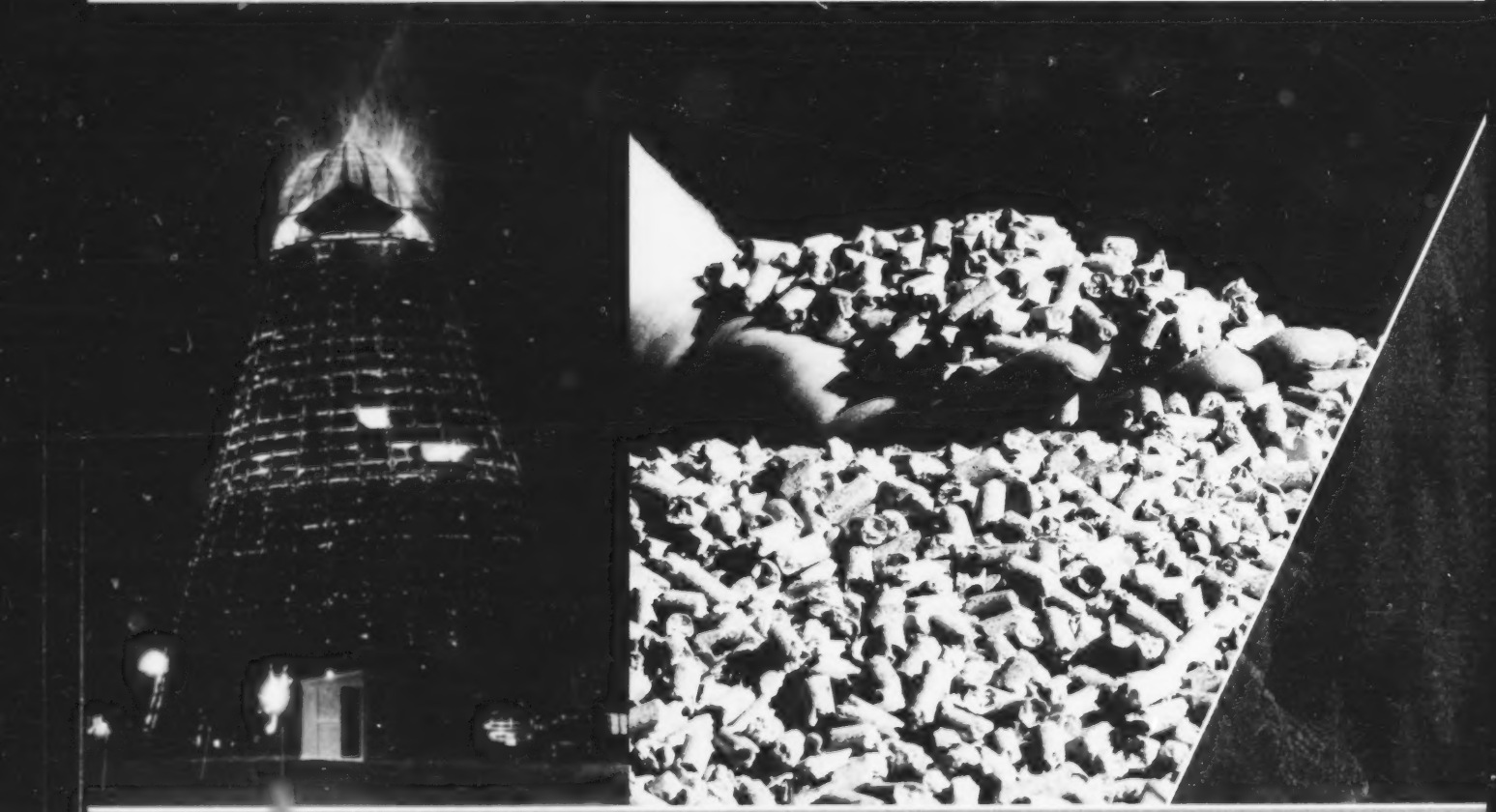
Bioenergy options for woody feedstock: are trees killed by mountain pine beetle in British Columbia a viable bioenergy resource?

B. Stennes and A. McBeath

Natural Resources Canada • Canadian Forest Service
Pacific Forestry Centre • Victoria, British Columbia
Information Report • BC-X-405



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2006

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www.pfc.cfs.nrcan.gc.ca

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ISSN 0830-0453
ISBN 0-662-43996-1
Printed in Canada

Microfiches of this publication may be purchased from:
MicroMedia Inc.
240 Catherine Street, Suite 305
Ottawa, ON K2P 2G8

Library and Archives Canada Cataloguing in Publication

Stennes, Bradley Kenneth, 1963-
Bioenergy options for woody feedstock : are trees killed by mountain pine beetle in British Columbia a viable bioenergy resource? / Brad Stennes and Alec McBeath.

(Information report ; BC-X-405)
Includes bibliographical references: p.
Includes abstract in French.
ISBN 0-662-43996-1
Cat. no.: Fo143-2/405E

1. Forest biomass--Economic aspects--Canada. 2. Biomass energy industries--Canada. 3. Pine--Diseases and pests--Economic aspects--British Columbia. 4. Mountain pine beetle--British Columbia. I. McBeath, Alec II. Pacific Forestry Centre III. Title. IV. Series: Information report (Pacific Forestry Centre) BC-X-405

TP339.S73 2006 333.95'39 C2006-980206-8

2007-01198/

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Acknowledgements

This study was funded in part by Natural Resources Canada/.Canadian Forest Service and NRCan's Mountain Pine Beetle Initiative. We would also like to thank Steve Glover for his very helpful comments on earlier drafts of the study, which contributed to a much better final report.

Abstract

Commercial energy production from woody biomass is receiving considerable attention due to a host of factors. Demand-side drivers include upward pressure on the cost of traditional energy sources and an increased awareness of the negative effects of generating energy from these traditional (commercial) sources. On the supply side, woody biomass sources are increasing as a result of insect outbreak, fires or measures to minimize the risk of such events. Except in special cases, biomass energy technologies still cost more than energy production from fossil fuels, necessitating regulatory or economic instruments to increase their adoption. Following a general analysis of the drivers and instruments to facilitate bioenergy uptake we examine the economic issues associated with bioenergy production resulting from the mountain pine beetle outbreak in the British Columbia interior.

Résumé

La production d'énergie commerciale dérivée de la biomasse forestière fait l'objet d'une attention considérable en raison de plusieurs facteurs. Parmi les facteurs liés à la demande, mentionnons la hausse constante des coûts des sources d'énergie traditionnelles, ainsi qu'une plus grande sensibilisation à l'égard des effets négatifs de la production d'énergie à partir de ces sources conventionnelles (commerciales). Du côté de l'offre, les sources de biomasse forestière sont à la hausse en raison des invasions d'insectes, des incendies ou des mesures visant à réduire le risque de telles occurrences. À l'exception de cas particuliers, les technologies liées à l'énergie de biomasse sont plus onéreuses que l'énergie produite à partir de combustibles fossiles puisqu'elles nécessitent des instruments réglementaires ou économiques pour favoriser leur adoption. C'est pourquoi, à la lumière d'une analyse générale portant sur les facteurs et les instruments requis pour faciliter l'implantation de la bioénergie, nous avons examiné les questions économiques liées à la production bioénergétique découlant de l'infestation par le dendroctone du pin ponderosa en Colombie-Britannique.

1. Introduction

The production of energy from woody biomass is the oldest use of wood and is still the main source of energy for heat and cooking in much of the developing world. Globally, in 2003, 53% of the roundwood harvested went to fuel wood primarily for thermal energy in inefficient processes (FAOStat 2004). The focus of this analysis is the commercial use of woody biomass for energy production, a less common but increasingly popular use of this resource due to improvements in technology, increasing prices of more traditional energy sources and an ever increasing recognition of the negative externalities associated with other sources of energy. It remains more costly to produce energy from renewable sources, except in special cases, necessitating the use of either regulations, market instruments or some combination of the two.

The Nordic countries of the European Union have been at the forefront of commercial applications for woody biomass, using an array of policy instruments (subsidies, taxation and hard targets) to support the development of both supply and demand for renewable energy. This is a region where public policy has brought biomass energy into the mainstream. Canada has considerable generating capacity for producing energy from woody biomass as well. Most Canadian energy from wood is based on residual streams used internally for manufacturing processes within the forest sector. One exception is the production of an intermediate product, wood pellets, which is a rapidly growing industry in Canada. The final destination for most of the pellet production is the Nordic countries where the final conversion to energy is done. The low cost of fossil fuel resources in Canada makes further development of domestic biomass energy outside the forest sector quite challenging. Figure 1 shows the development of the different energy streams in Canada over the past century.

The main purpose of this study is to examine the economic feasibility of increasing the use of woody biomass for energy outside internal use in the forest sector. Other studies have focused on new "state-of-the-art" technology, we instead focus on technology that is currently in use in North America (see the Appendix for a description of various technologies). We will focus on the specific case of using fibre resulting from the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) epidemic occurring in the northern and central interior of British Columbia. As background to this analysis we examine the main drivers for renewable energy and study the array of policy instruments used to facilitate the uptake of renewable energy.

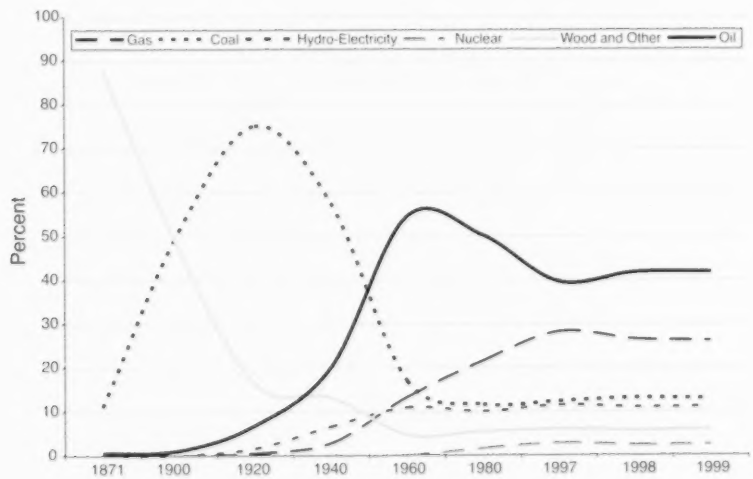

Figure 1. Percentage of Canada's energy consumption by fuel source (1871-1999)
Source: NRCAN (2002)

2. Current status and drivers for increasing the use of biomass energy

Biomass energy, as one of a number of renewable energy sources, is receiving greater attention in much of the developed world, and increasingly in the developing world. There are a number of renewable energy forms that are being developed to meet the demand for alternatives to fossil fuels. The benefits from renewable energy include environmental improvement, fuel diversity and economic security and regional and local economic stability. Specific drivers for increasing energy from woody biomass in a North American context include the development of alternative markets for currently non-economic wood fibre sources, and the associated economic benefits to rural resource dependent communities. Examples of non-economic wood fibre sources include small diameter thinnings resulting from hazardous fuel reductions and those supplies of salvage materials outside the traditional economic margin due to stand-level forest mortality.

2.1 Global Drivers

The potential for public benefits has generated much of the worldwide interest in renewable energy sources; understanding the reliance on energy and the value of energy in the economy helps to clarify the possible magnitude of these public benefits. For example, when the price of a barrel of oil reached $50[1], an estimated value of annual world primary energy consumption was 3.5 million millions of dollars or $3.5 X 10^{12}$. The expenditure on energy fuels is large and therefore the price is an extremely important aspect of the energy market as it has a large effect on the cost of production in the world's economies. Representative prices from the US market over the past three decades for coal, natural gas and oil, all converted to million British thermal units (MMBtu) and adjusted for inflation are given in Figure 2.

Despite the rise in the price of crude oil in late 2004, the real price (adjusted for inflation) was still well below that reached in the early 1980s, which at its peak reached a spot price of over $80 (real 2004 US dollars per barrel). Given current technological realities, oil in particular and fossil fuels in general are a necessity for growth in many of the world's economies. Although fuel sources for energy production may change with new technologies, growth in the global economy will lead to increased energy consumption. The Energy Information Administration (EIA) forecasts an increase in total world energy consumption from all fuel sources between 2001 and 2025 of about 50%. Although developing countries will lead that growth, all regions are forecasted to contribute to an increased demand for energy into 2025 (EIA 2004).

2.1.1 Energy Independence

There appears to be a significant link between oil price increases and macro economic downturns (Toman 2002) and fear of price shocks has been a policy driver since the first oil crisis in the 1970s (see Figure 2). Subsequent price shocks throughout the 1980s, mid 1990s, in 2000 and again in early 2005 where the price of oil is approaching the price peak of the 1980s (after adjusting for inflation), have all contributed to substantial concern over energy security.

In the short term, oil price spikes are not followed by large drops in consumption, indicating that short-term demand for oil is inelastic. Although the demand for oil is price inelastic in the short term, in the long term, as substitutes are developed, alternative fuel choices provide flexibility and the economic impact of oil price shocks will be less. Figure 3 shows the portion of world energy consumption made up by alternative fuels. Only 15% of the fuels are non-fossil fuels, and nuclear energy is almost half of that.

1 British thermal units (Btu) converted to oil equivalent at 1 Quadrillion Btu = 172 million barrels of oil equivalent. This is an estimate of the value of energy based on the price of oil and Btu generated from different fuels at energy consumption levels from 2001 (see Figure 3). This is a rough estimate as energy is generated from a number of fuels such as oil, coal, natural gas as well as a number of different renewables which all have their own prices and quantities.

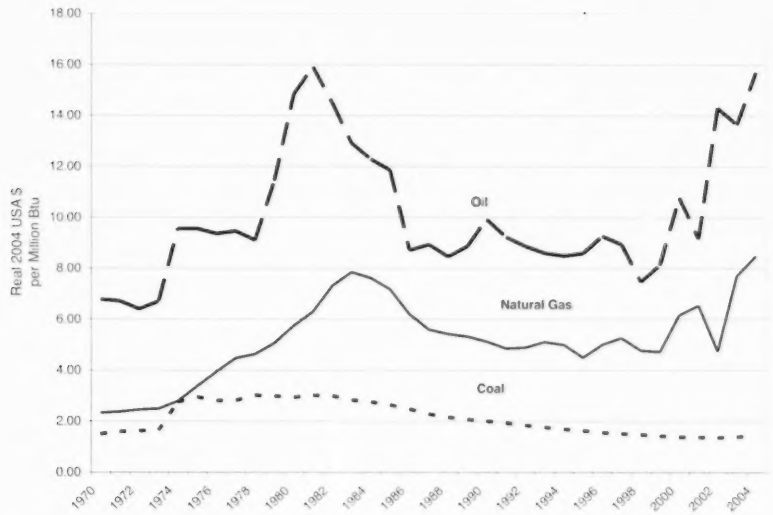

Figure 2. Annual average energy prices, real 2004 US$ per MMBtu
Source: EIA (2005)

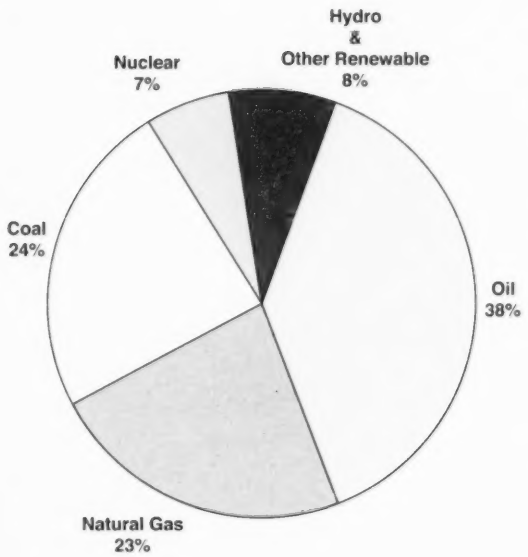

Figure 3. Total world energy consumption by fuel type (2001) (percentage of total 403 quadrillion Btu)
Source: EIA (2005)

Given that much of the world's oil reserves are located in politically unstable regions, independence from imported oil is a driver for the development of new energy sources. Toman (2002) suggests it is unrealistic to assume that the USA will be able to eliminate overseas oil imports or that the world can substantially reduce its use of oil. Policy to reduce dependence on imported oil is a priority for many nations around the globe, but especially in the USA. Many nations are encouraging their industry to become more efficient in terms of energy use (Figure 4) and many governments are either involved in the development of renewable energy themselves or are creating incentives for the development of alternative fuels (see Section 3).

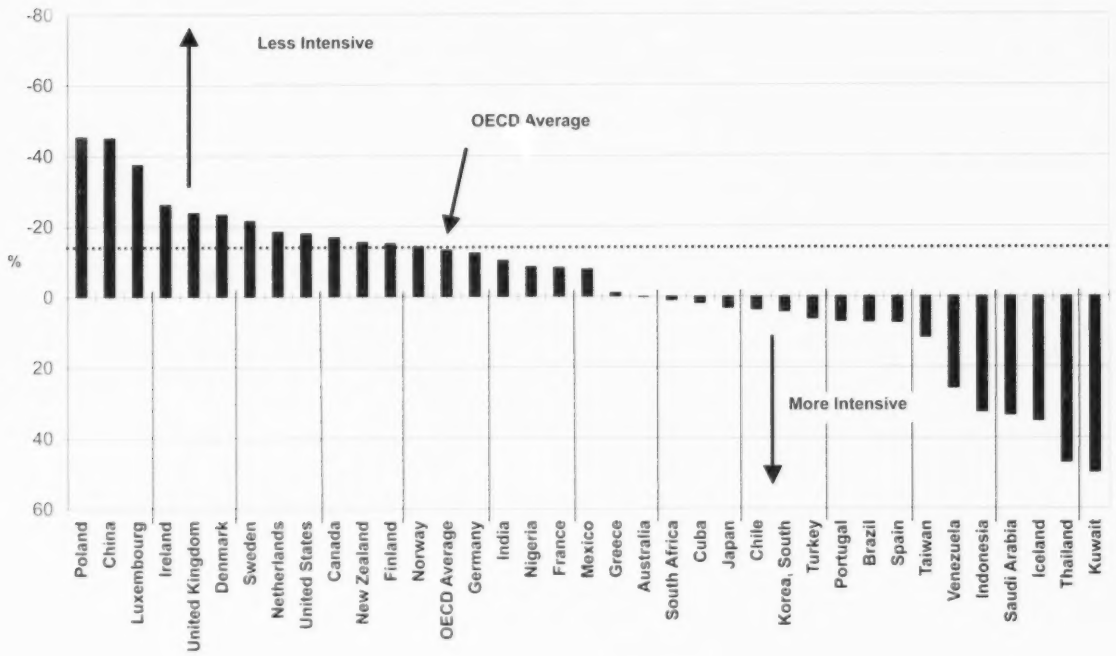

Figure 4. Percentage change in energy intensity - selected countries (1991-2002) where intensity is total primary energy consumption per dollar of gross domestic product, Btu per 1995 U.S. Dollar
Source: EIA (2005)

2.1.2 Environmental Improvement and the Kyoto Protocol

The 25 members of the European Union and 120 other countries have now ratified the Kyoto Protocol of the United Nations Framework Convention on Climate change (UNFCCC) and 41 countries (EIA 2004) have committed to a reduction in greenhouse gases. Although the United States and Australia did not ratify the protocol, it had sufficient support, and came into effect on February 16, 2005.

The responses of individual countries to the Kyoto Protocol are yet to be determined, and the net impact on global markets is impossible to predict with accuracy. There is a global interest in alternative energy production technologies and that interest increases when there are additional benefits to ratifying countries; such benefits would be generated under the Kyoto Protocol from renewable, carbon-neutral (or carbon-free) energy technologies.

International efforts to reduce global warming are changing how energy is produced, although world greenhouse gas emissions are still rising, and emissions are rising at increasing rates (see Figure 5 for CO_2). The purpose of the Kyoto Protocol is to reduce the growth in human contributions of greenhouse gases. The problem is that policy makers are reluctant to tax fossil fuels when that might restrain economic growth.

Slowing climate change will be a long-term undertaking. It is generally recognized that the search for alternative energies will require a huge effort, in terms of money and time, to develop technology. Biomass energy may be one of the cheaper and more practicable alternatives.

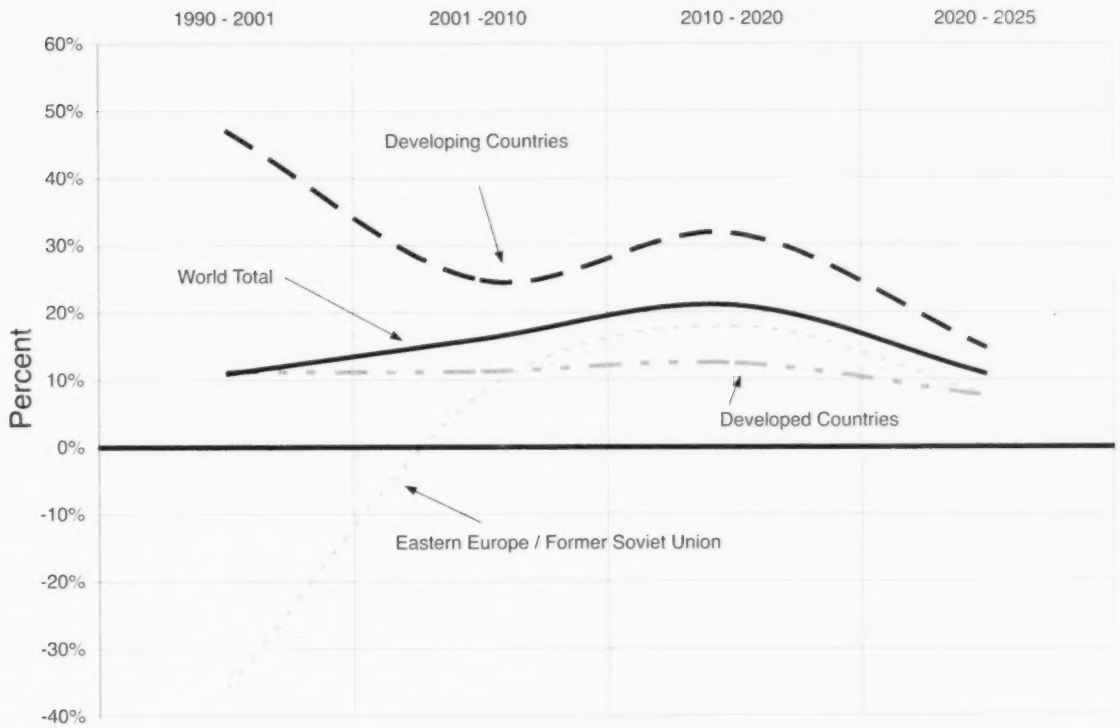

Figure 5. Forecasted percentage growth in CO_2 emissions by region in four time periods (1990 - 2025) Source: EIA (2005)

2.1.3 Carbon credits under the Kyoto Protocol

Among the benefits of forests, the Kyoto Protocol recognizes that growing trees absorb carbon in the process of photosynthesis and that vast quantities of carbon are stored in forests. If stocks of carbon are increased through afforestation or reforestation then that carbon has been removed from the atmosphere. In lieu of this carbon storage, the Kyoto Protocol may give credit that effectively reduces the amount by which a ratifying country has to reduce carbon emissions from fossil fuels. This mechanism is meant to provide flexibility and thereby reduce the costs of meeting emissions targets. Although there is an issue of how permanently this carbon is stored and the timing of when land is forested is critical in the actual accreditation, this is a potential benefit of forest management.

Although burning of trees or biomass releases carbon, this carbon was sequestered in the vegetation from the atmosphere as the trees grew. As long as replacement vegetation growth occurs, there is no net release of carbon when biomass is burned. This is why energy from biomass is considered carbon neutral under the Kyoto Protocol. Although economists argue that the timing of sequestration versus release is important, application of a discount rate to carbon is an aspect not considered in the accounting rules of the protocol.

2.2 Status of bioenergy use in Canada

Renewable energy capacity in Canada is 93,000 MW if large-scale conventional hydro projects are included, with biomass comprising 8.5% of this capacity (Nyboer *et al.* 2004). Of the total biomass energy produced, most is used internally by forest companies as cogeneration in pulp mills. The feedstock is either in the form of residues (bark, shavings and sawdust) or black liquor, a byproduct of the pulping process at kraft pulp mills.

Concentrating specifically on biomass electrical production, the province with the greatest capacity is British Columbia, with nearly 50% of the national total, followed by Ontario with 27% (Figure 6). The largest stand-alone facility in the country is at Williams Lake in the interior of British Columbia, and this facility has been in operation since the early 1990s. Actual biomass-fuelled electrical production in British Columbia was reported to be in excess of 600 MW in 2002 (BC Hydro 2002), and it was also estimated that 1.6 million BDT (bone dry tonnes) of wood waste was still being incinerated in beehive burners with no energy recovery. In a more recent study, total installed capacity for electrical production from woody biomass was estimated at 670 MW for British Columbia (Nyboer et al. 2004).

Larger operations can collect sufficient quantities of wood waste from manufacturing operations to justify conversion to productive energy due to economies of scale. This is applicable to integrated pulp and paper mills, very large sawmills and communities hosting a number of smaller mills within a confined radius. By contrast, most sources of forest waste are widely distributed over large areas. This results in relatively high cost for collection and transport for this high-bulk, low-value resource, and the subsequent economics of this situation limit the opportunities for productive use.

BC Hydro, as part of their 2004 Integrated Electricity Plan, analyzed the various future supply options for adding generating capacity to British Columbia. As the province has mandated a proportion of new supply come from clean energy sources (renewable portfolio standard approach, see Section 3.1 for more details), many supply types are examined in this report. A summary of the cost ranges by supply type recreated from that analysis is given in Figure 7.

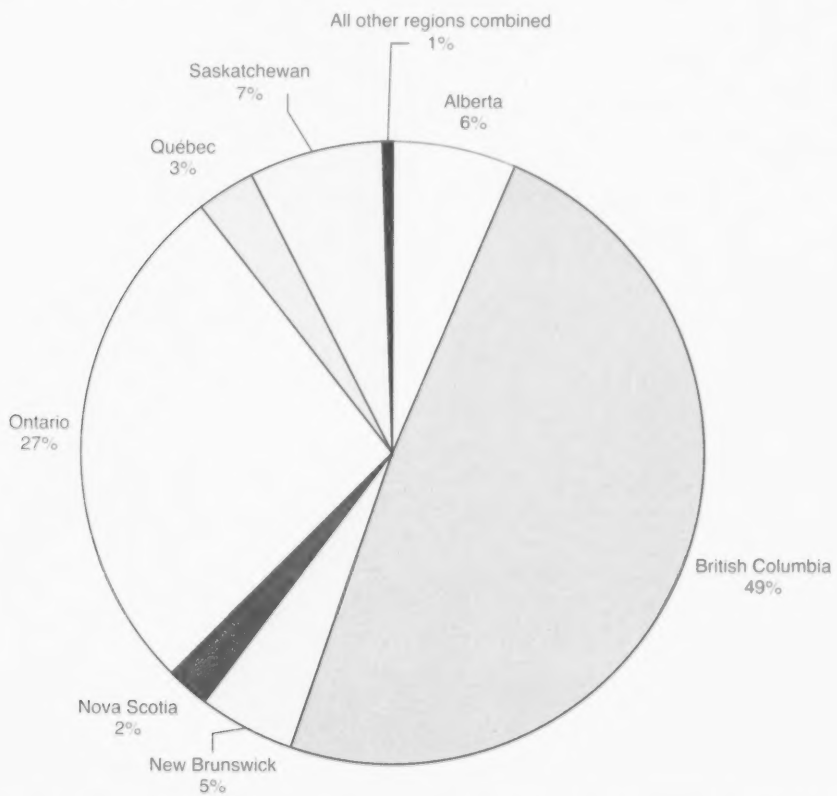

Figure 6. Biomass energy production capacity in Canada by region (2003) percentage of total 7.9 million kW. (This estimate includes both electrical production and thermal energy production, which is why it is higher than the 670 MW reported earlier.)
Source: Nyboer et al. (2004)

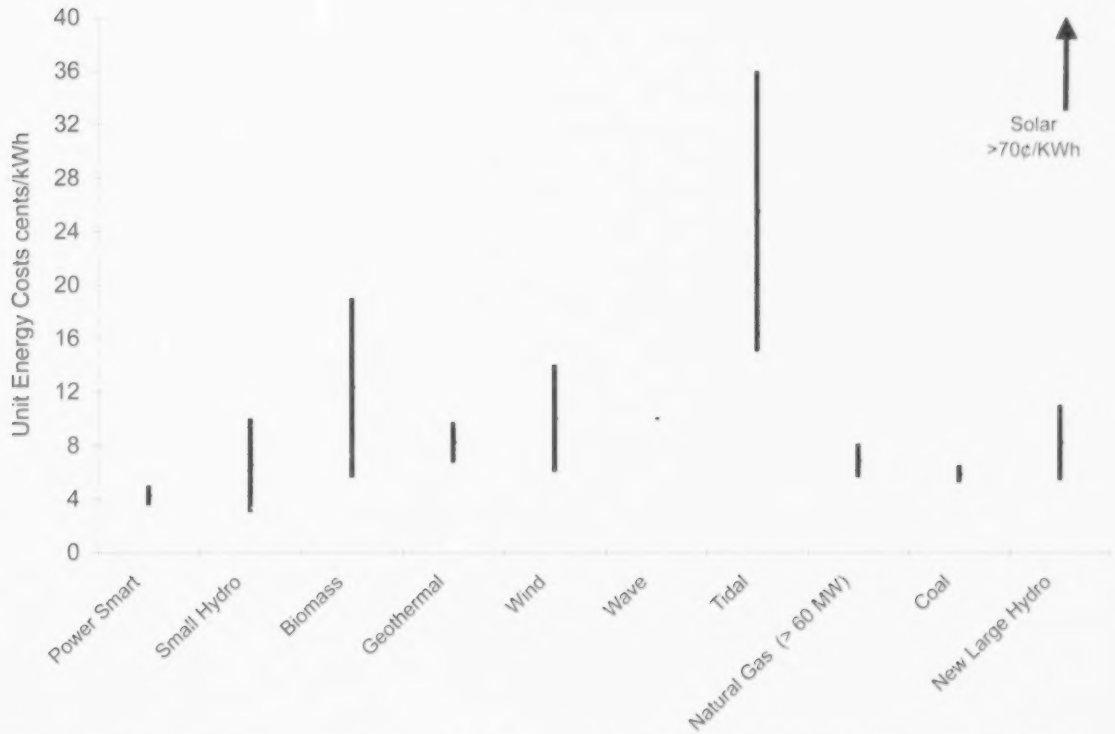

Figure 7. Levelized cost ranges for various electrical supply types for British Columbia. Levelized cost is the present value of the total cost of building and operating a generating plant over its economic life, converted to equal annual payments. Costs are levelized in real dollars (i.e., adjusted to remove the impact of inflation).
Source: Based on estimates in BC Hydro (2004a)

3. Economic and policy incentives

Bioenergy, and most so-called "green" technologies for energy production, are higher cost sources than baseline technologies for new generation (i.e., natural gas fired electricity generation). As many jurisdictions (including British Columbia) have signalled the need to increase the proportion of green energy in their production portfolios, regulatory or market intervention is required. There is a mixture of regulatory methods, market-based instruments and mixed schemes in use around the world to increase green energy (which includes bioenergy) use and development. In this section we will discuss a number of these instruments.

The most direct means to encourage the use of biomass in energy is through "command and control" regulations, which simply prescribe activities that must be adhered to. The main problem with the command and control method is that environmental objectives are met at very high costs, and there are no advantages to the polluter in exceeding the environmental objective. More efficient methods exist to control environmental problems. Economists generally prefer market-based approaches to command and control approaches to increase the uptake of green technologies.

Market-based approaches include subsidy and taxation schemes, certification (green pricing) and tradable emissions permit schemes for CO_2 emissions with biomass energy treated as carbon neutral. Subsidy and taxation can be effective at meeting environmental objectives such as reducing emissions. However, unless information about industry marginal cost and benefit curves are known (i.e., to set Pigovian Taxes), specific emissions targets are met only by chance.

On the demand side, certification schemes also utilize market forces to achieve environmental improvements. In this case it is consumer demand that drives environmental change. If consumers can be *reliably* informed (i.e., through objective auditing and labelling of final products) that goods or services are produced in a predefined manner, they can help drive change through purchasing decisions. Electrical utilities have utilized this concept to develop renewable energy supplies through "green-pricing" systems in both the US and Canada. Green pricing allows consumers to pay a price premium to receive new incremental electricity from a certified supply of renewable energy.[2] Certification schemes by themselves, being voluntary programs, can't ensure that specific regional environmental targets are met.

3.1 Canada

The Canadian experience with renewable energy shows that in general the cost of producing energy from renewable sources still exceeds the cost of conventional energy from fossil fuels, excluding environmental or external costs. As would be expected given the cost, renewable energy (excluding conventional hydro) accounts for roughly 3% of energy produced in Canada (Tampier 2004) and incentives are still required to increase development in the sector.

The purpose of this section is to characterize some incentive programs targeting green energy in general and biomass energy in particular. This will not be an exhaustive listing, and many new programs are likely to be developed in the near future now that the Kyoto protocol has been ratified and Canada works to meet greenhouse gas targets. In terms of incentives to encourage the development of biomass energy production, policy in Canada has been a byproduct, for the most part, of policy to reduce greenhouse gases as opposed to a policy to support energy autonomy. There are incentive policies in place in Canada that have emerged as a result of the Action Plan 2000 on Climate Change and the 2002 Climate Change Plan for Canada. In addition there are both environmental policies and economic programs that existed prior to Kyoto that provide incentives to reduce air pollution. For example, provinces require permits or licenses for industries that emit into the environment and the costs of these permits will vary with emission levels, resulting in an internalization of the environmental costs caused by industry. There is an accelerated capital cost allowance for many types of renewable energy under the Income Tax Act that began in the 1980s, and it was announced in the 2005 federal budget that this capital cost allowance rate has been increased from 30% to 50% (Department of Finance Canada 2005). In addition, there are programs that encourage economic development that would include the development of new technologies that would reduce greenhouse gases. One specific example is the Aboriginal and Northern Community Action Program aimed at reducing the reliance of Northern Aboriginal communities on diesel power generation. There are also a number of research and development programs in place that will help develop renewable energy such as the Technology Early Action Measures under the Climate Change Action Fund and the Climate Change Technology and Innovation Program. There are other programs supporting economic development in Canada and each province will have its own environmental and economic development programs.

To encourage renewable energy, governments can alter the market conditions so that either the cost of environmental degradation or the benefits of reduced emissions are considered in market outcomes. On the other hand, government can dictate outcomes by prescribing how activities are undertaken. Renewable energy policy in Canada involves provincial electrical regulatory commissions and Crown corporation utility providers in addition to federal, provincial and municipal governments. All of these levels of decision makers are potentially involved in the programs considered in this section.

Grant programs with financial incentives for renewable energy production are meant to aid research and development or establish infrastructure and create partnerships with industry to establish commercial renewable energy prototypes. The ethanol expansion program from Natural Resources Canada has

2 Green pricing is offered by 15% of US electrical utilities, and is available in 34 states (Bird and Swezey 2004). In Canada green pricing is offered by Enmax and green tags by Epcor in Alberta and in the Kooteneys of British Columbia.

established funding for construction of new fuel production facilities and the Wind Power Production Incentive pays from 0.8 to 1.2 cents per kWh depending on the project start date. The Renewable Energy Deployment Initiative provides a portion of the capital costs for renewable energy systems and biomass is listed as a specific target fuel source.

Three promising programs for renewable energy are being established in regions across the country. Often regional programs, such as net metering and green pricing, are initiated by the local electrical utility.

First, net metering is when a utility gives individual power users credit for producing renewable power. Prior to net metering individual power producers could not bank power in peak production times. For example, a wind producer had no incentive to produce power in excess of what they could use because it could not be stored. With net metering, excess power is fed back to the grid and producers are given credit. Most provinces are either researching the benefits of this scheme or have already established net metering programs. Alberta has a deregulated power market and as such power producers have open access to supply power to the "balancing pool," which will provide the same access to the provincial power grid as a net metering program.

Secondly, green pricing or green marketing (also called "green tags," " renewable energy certificates," "renewable obligation certificates," "tradeable environmental certificates," etc.) is a policy that attempts to put a price on the additional environmental benefit of reduced greenhouse gas emissions and return this benefit to a renewable energy producer to offset the typically higher cost of producing green energy. These programs can be as simple as consumers paying more for electricity produced by renewable fuel sources.[3] Other programs involve creating a green asset (green tag) that can be purchased independent of energy as a third party subsidy for green producers. Alternative forms of the program involve provincial mandates that sellers of electricity obtain a certain amount of renewable energy credits. These programs are unique in that electricity providers have the flexibility to earn credits by producing green power or buy credits from another producer, either way guaranteeing a market for green power. These types of programs are beginning to appear across Canada, including Ontario's Evergreen Green Power Program and EPCOR's Green Tags[4].

Finally, many of the provincial policies on renewable energy are via the Crown corporations that provide power or the arm of the provincial governments that regulate power in the form of renewable portfolio standards (RPS). These are targets set by the provinces for green power development and these programs are being developed in some form in all provinces and territories. BC Hydro, for example, has a 10% target for green electricity, including 50% of new supply between 2002 and 2012 coming from "clean" electricity. As a result of this initiative, BC Hydro has undertaken partnerships with industry to both help fund the capital costs of biomass cogeneration facilities and pay for internal power consumed through load displacement agreements. Also notable is the Alberta experience where the renewable target of 125 MW was enacted in the *Small Power and Research and Development Act* (1988).

3 In some cases it must be certified that this energy is produced from renewables and there are a number of issues surrounding what constitutes green energy.

4 EPCOR's Merchant and Capital subsidiary offers renewable energy products, called Green Tags, to mid- and large- sized commercial customers. These renewable options are offered through the EnVest Program.

3.2 European Union

The European Union (EU) adopted a directive in 2001 to promote renewable energy production in internal electricity markets (IEA 2005). The target is to generate 22.1% of electricity and 12% of all energy from renewable sources by the year 2010. Although this is very much a regulated target, individual countries within the EU were given country-specific targets and discretion on how to meet the targets, many choosing to use market incentives. There are many programs to support green energy development throughout the EU, most notably feed-in tariffs which guarantee a price premium for renewable energy production. It should also be noted that many of these countries had well entrenched systems in place prior to this directive, most notably the Nordic countries.

Carbon taxes on non-renewable energy sources have been used in the Nordic countries and the Netherlands since the early 1990s. The countries that have specific taxes on CO_2 include Denmark, Finland, Italy, Norway, the Netherlands and Sweden (IEA 2005). Finland was the first country to institute carbon taxes in 1990, although other Nordic countries (e.g., Sweden) followed suit in 1991. In the case of Sweden, CO_2 emissions have risen since 1990, although at a slower rate than would have been the case without the taxes (Bohlin 1998). The effectiveness of the carbon tax in Sweden has been weakened by a reduction in the rates paid by industrial users.[5] In addition to a carbon tax, Sweden also levies taxes on energy and sulphur, although for competitiveness reasons industry is exempt from the energy tax. Biomass energy is exempt from all of these taxes in Sweden, leading to a relative cost advantage versus the case in an instrument-free market situation. There are many other programs in Sweden that are aimed at increasing biomass energy uptake as well including (IEA 2005):

- Green certificates scheme in which tradable certificates are generated by select green energy sources, with one certificate produced for each MWh of production. Consumers are required to purchase a certain number of certificates or face a fine.
- Tax breaks to individual homeowners who install pellet or wood burning furnaces.
- Feed-in tariffs, which guarantee additional support above the market price of electricity for small independent power producers using wind or biomass.
- Energy research and development program

3.3 United States

3.3.1 Biomass Electricity

There are a host of instruments in use in the US at either the federal or state level influencing biomass energy production or use. At the federal level two programs were introduced in the early 1990s as part of the Energy Policy Act of 1992, providing incentives for electrical generation from green energy sources (including some biomass). The Renewable Energy Production Incentive (REPI) paid 1.5 cents per kWh (real 1993 currency) to eligible facilities owned by state and local governments. Eligible facilities included solar, wind, geothermal or biomass. Closed-loop biomass was classified as Tier 1 and open-loop biomass as Tier 2, with Tier 2 facilities receiving funding only if Tier 1 applicants did not exhaust available program funds. Facilities in the program will continue to receive payments until 2013, subject to available funds, but as of Sept 2003 no new applications are being accepted. In 2002 REPI paid out $1.8 million to Tier 1 facilities and $3.0 million to Tier 2. Only a single wood waste facility received funding in 2002.

5 Carbon taxes were instituted in Sweden in 1991 with an initial rate of $US 133/tonne C. This was changed two years later to a differential rate with industry charged $43/tonne and consumers $160/tonne (Bohlin 1998).

The Renewable Energy Production Tax Credit allowed the same 1.5 cents per kWh (real 1993 currency) incentive to private facilities in the form of a tax credit available to facilities generating electricity from wind, closed-loop biomass, or poultry waste. This was initially a 10-year program as well, but was renewed in 2004 for another decade and the list of eligible energy sources has been expanded to include open-loop biomass, solar, municipal solid waste, geothermal, and small irrigation power. The original incentives for closed-loop biomass, wind and poultry waste facilities were extended for 10 more years, while the tax credit is only half the size for the newly eligible types (including open-loop biomass) and will only last 5 years (Database of State Incentives for Renewable Energy 2004).

At the state level in the US a relatively common instrument for supporting environmentally friendly electricity generation in green pricing. These are voluntary programs where consumers pay a premium for electricity generated from environmentally friendly sources. These programs are available from over 500 utilities in 34 states, and over 50% of all US consumers can purchase green power, with the mean level of premium being 2.6 cents per kWh (Bird and Swezey 2004). As of 2003, 265,000 customers in the US participated in green pricing (Bird and Cardinal 2004, as reported in Bird and Swezey 2004).

3.3.2 Ethanol

Ethanol production in the US receives public support from numerous programs at the federal and state level. The most notable federal support for ethanol is the excise tax exemption on gasoline when blended with ethanol. This exemption dates back to 1979, when the excise tax of 4 cents/gallon was foregone on gasoline blends containing at least 10% ethanol (known as E10). As of 2004, the exemption rate is 5.2 cents/gallon for E10 and this also applies to proportionally lower rates at blends with less ethanol (California Energy Commission 2004). A second federal program is the small producer credit, enacted in 1990, which provides an income tax credit of 10 cents/gallon produced up to 15 million gallons of production. This credit is only available to those with a maximum annual production of 30 million gallons.

In California, 2003 legislation banning methyl tertiary butyl ether as a gasoline oxygenate has created a huge demand for ethanol. Ethanol is currently (as of 2004) the only state-approved additive, resulting in most gasoline in the state being sold with 6% ethanol. This has caused California to become the largest US consumer of ethanol, with demand from the state at approximately one-third of total US productive capacity (California Energy Commission 2004). There are incentives for ethanol production or consumption in 36 states, with the most common approaches at the state level being either production payments (similar to REPI), or tax credits against state income tax. These, in combination with the federal excise tax, are generally calibrated to provide ethanol at a price that is competitive with gasoline.

A nonenvironmental benefit of support for the ethanol industry is provided to the agricultural sector, as an additional markets for midwest crops such as corn. Support programs aimed at producing ethanol from dedicated crops (principally corn) do have critics, principally D. Pimental of Cornell University in Ithaca, New York, who published a study (Pimental 1991) estimating that ethanol has a negative energy balance ratio of 1.29:1, meaning that ethanol uses more energy to produce than it can generate. Pimental is still a staunch critic of US ethanol production, although subsequent studies such as Shapouri *et al.* (1995) refute Pimental's findings, estimating a positive net energy balance ratio of 1:1.3.

4. Biomass Feedstock Opportunities in Forestry

The use of woody biomass for commercial[6] energy production has tremendous potential on a global scale. Uptake has generally been low, with the main exception being northern Europe (as discussed in section 3), which has effectively utilized economic incentives to support biomass energy production. The most important factor for economic feasibility in biomass energy production is the cost associated with the collection, handling, transportation and storage of the biomass feedstock. Variability in procurement costs between feedstock that is currently in the waste stream (i.e., a co-product associated with another process) and that which is not leads to the wide cost ranges typical of biomass feasibility studies. In Canada, most success in using woody feedstock for energy production is in processing residuals, and these are generally used internally by the forest industry (most notably for energy production in pulp mills and heat for drying kilns in sawmills). In many of these cases, valuation of the biomass feedstock at its opportunity cost leads to zero or even negative costs (benefits), as tipping fees or treatment costs are avoided. The aggregate cost of collecting, treating and transporting the feedstock for the express purpose of energy production is generally prohibitive given market costs for energy. In this section the costs of woody biomass feedstock are reviewed and summarized, focusing on the economics of using fibre available in the British Columbia interior as a result of the mountain pine beetle epidemic and associated salvage.

4.1 Synthesis of Feedstock Studies in the western US

There has been increasing recognition in the western US that large areas of forest are in need of hazardous fuels reduction to minimize the risk of wildfire (USDA 2001). This shift to so-called proactive wildfire management has led to numerous studies on options to utilize this often subcommercial source of fibre, usually small-diameter forest thinnings. As one such option is biomass energy production, such studies may be helpful from a Canadian perspective. The estimated biomass feedstock costs from a number of these studies and a specific US study of salvage harvest for energy are given in Table 1. These estimates are generally provided as a range of costs, and estimate the roadside costs or the delivered costs or both. The distribution of costs and the average costs are provided.

Table 1 presents the costs of biomass feedstocks that are mostly the result of forest thinnings, with the exception of the study by Ince *et al.* (1984) which did examine the costs of salvage harvesting lodgepole pine following an outbreak of mountain pine beetle. For the purposes of comparison all of the costs have been converted to real (2002) Canadian dollars per bone dry tonne (BDT). For the estimates that are expressed only as roadside costs, we added $10/BDT (conservative) to account for transport, and averaged the "delivered" costs for the six studies which resulted in a mean delivered cost of approximately $90/BDT.

Table 1. Biomass feedstock costs in the western US (2002 $Cdn/BDT)

Source	Roadside			Delivered		
	Low	High	Mean	Low	High	Mean
Ince et al. (1984)	56.81	137.83	74.60	72.76	154.39	90.08
McNeil Technologies (2003)	39.45	65.39	55.95	-	-	-
Zachritz et al. (2000)	-	-	-	50.40	59.11	54.75
Lynch and Mackes (2002)	93.59	145.76	119.68	-	-	-
Klepac and Rummer (2002)	96.99	130.91	113.95	-	-	-

6 We define "commercial" energy production as an industrial process of converting wood to energy or heat. Wood is, and always has been, used for heating and cooking in most of the world.

4.2 Mountain Pine Beetle Epidemic – Feedstock Supply Potential

Early estimates of the potential fibre supply from the mountain pine beetle epidemic predicted that approximately 500 million m^3 of timber would be killed in the period 2005 to 2008 (BCMOF 2004(a)). In addition to very large volumes, the outbreak is spread over a very large area (Figure 8). It is anticipated that existing processing sectors can use much of this timber volume, but approximately 200 million m^3 of this total is expected to remain unsalvaged over the next decade unless creative new uses can be found for this massive volume of fibre. Although this indicates a large potential supply of feedstock for energy purposes, much of it will be uneconomic. The supply potential of this feedstock will be defined by two economic margins – the intensive and extensive margins. Availability at the intensive margin arises from more fully utilizing fibre on a given area of land, i.e., increased utilization. Availability from the extensive margin arises from expanding the area harvested. Most of the available economic supply of feedstock for energy is that available at the intensive margin, including residuals, and low-valued timber within stands with a mix of higher quality stems that would not be of sufficient grade to justify manufacturing activities.

A further complication is that the longer beetle-killed timber remains standing, the less options are available for using the fibre. Eventually, the decomposition of this dead timber renders it useless, even for energy production. Therefore, as stands are salvage- harvested over time for processing into lumber or other traditional forest products, the supply of non-suitable timber per hectare will increase as higher proportions of trees within a stand fall below the quality threshold for lumber production or other manufacturing.

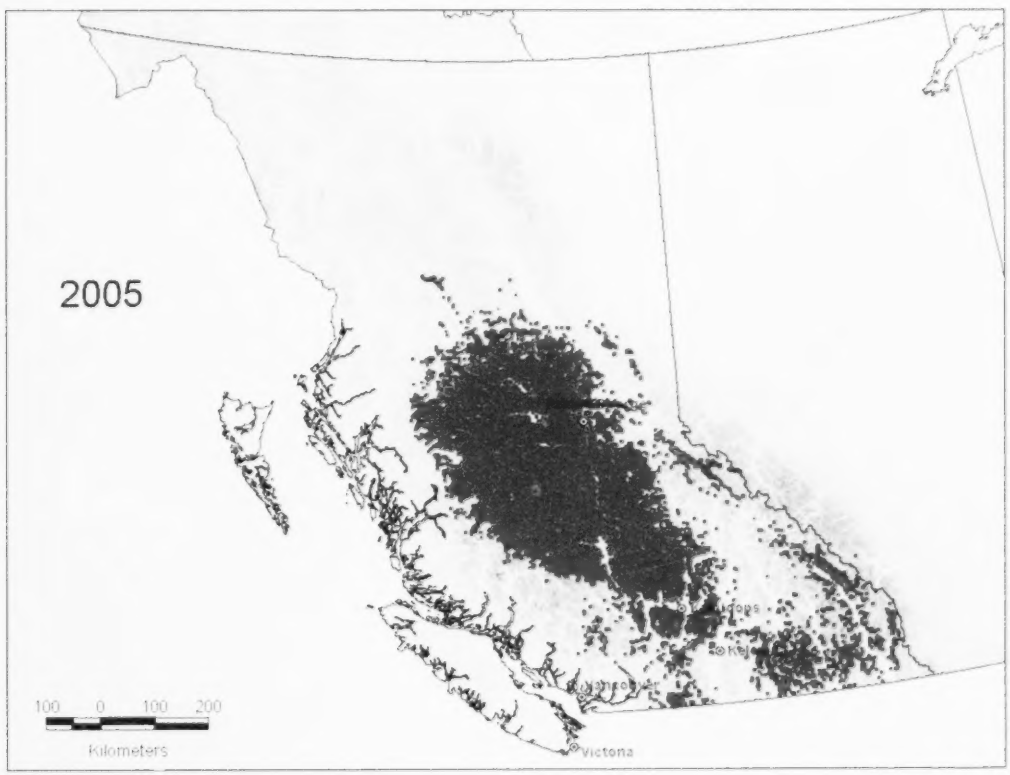

Figure 8. Area affected by mountain pine beetle outbreak in the interior of British Columbia

The first round of increases in annual allowable cut (AAC) in the three most heavily impacted timber supply areas (TSAs – Prince George, Lakes, and Quesnel) of British Columbia's northern interior focused on existing licensees and traditional manufacturing activities. The increase of 5.3 million m^3 represented an increase of 42% over the pre-outbreak AAC of 13.2 million m^3 (British Columbia Ministry of Forests 2004(b)).[7] This is being met by a combination of increased utilization of present capacity of existing sawmills (i.e., adding a third shift to mills that were running two shifts) and an increased capacity from a number of new investments.[8] The residuals associated with this increase in manufacturing are the lowest cost fibre as they have already been transported to sawmill locations. As of 2005 some of these residuals are still considered surplus and are incinerated in beehive burners, which incurs costs and has no associated benefit in terms of energy produced. Investment in new capacity is being made to utilize this lowest cost form of woody feedstock.

It must be noted that increases in the supply of residuals are a temporary source of feedstock that will only be available as long as the harvesting uplifts remain. The British Columbia Ministry of Forests forecasts a reduction in timber supply after approximately 15 years to approximately 14% below the pre-outbreak AAC levels by the 2015-2017 period. This represents a harvest reduction of 7.1 million m^3 compared to the supply levels from the initial increases in AAC. Although future harvest levels are uncertain, even a return to a pre-outbreak harvest levels would entail a large reduction in harvest and therefore residuals. It is not economical to build facilities that require substantial capital and long payoff periods specifically to use this supply of beetle-killed fibre given the lack of long-term feedstock. The question is, are there opportunities to provide feedstock in this region after the AAC is reduced? Assuming some of the beetle-killed timber is still harvestable, what is the cost of a long-term feedstock supply through dedicated harvest? The other possibility is to provide feedstock after the beetle outbreak through afforestation of appropriate marginal lands in the region with fast growing plantation fibre. This is a separate issue and is not examined in this study.

An alternative use of processing residuals, rather than direct energy production, is to create a value-added product such as wood pellets, or other new "state of the art" products such as enzymatic ethanol or bio-oil (See Appendix for a description of these technologies). There are a number of pellet production facilities currently operating in the British Columbia interior that are making use of processing residuals, and capacity is rapidly expanding with increased processing in this region. A recent Swedish study (Hirsmark 2002) estimated the costs to produce pellets at a commercial scale (80,000 tonnes/year). This cost estimate is reproduced below following a conversion to Canadian dollars (Table 2). Note that the cost to procure feedstock in the example given here is zero. The cost of delivered feedstock must be added to the $44/tonne (dry tonnes of finished pellets) below to estimate the total costs of producing pellets.

Feedstock from harvesting a greater area of trees killed by mountain pine beetle will be more costly than fibre from processing residuals. The early estimate of available feedstock resulting from the mountain pine beetle outbreak is at least 200 million m^3. Although harvesting for lumber production can provide sufficient financial returns to develop harvest areas, transport fibre (logs or chips), reforest and pay economic rents, this is clearly not the case with biomass feedstock. This can be illustrated by examining the costs to procure feedstock in the northern interior of British Columbia (Table 3). As most energy feedstock is measured in Bone Dry tonnes (BDT) rather than cubic meters, the costs are expressed on that basis using a conversion factor of 2.44 m^3/BDT to provide results that can be compared with those in other regions.

7 The first set of uplifts are also AAC increases in a number of adjacent management areas, for a total AAC increase of 7.8 million m^3 across 12 management units, but we are focusing on the three most heavily affected management units (and the three with the most thorough analysis to this point) in this section.

8 There is a limit on how much commodity product can be manufactured, with the most limiting constraint being the ability of highly contested markets to accept large increases.

It must be noted that the $100/tonne value estimated here assumes that all of the costs (including reforestation) to deliver and chip logs are accounted for in the biomass feedstock costs. The only cost not included are payments to the resource owner (i.e., stumpage), which is not an appropriate cost as no economic rents are available in the energy production example. A tonne of dry wood chips delivered to existing facilities[9] can generate approximately 1,398 kWh of electricity (net), which means the value of electricity produced is approximately $70/tonne, using a price of $0.05 kWh^{-1}. This means that prior to accounting for any of the capital or operating costs of a generating facility, providing the feedstock already entails an overall net cost of $34/tonne.

These costs could be reduced if on-site chipping of whole trees is feasible. This will increase the yield for a given volume of logs by about 20% (Nagle, G.S. 1990. Technical Background Paper, Trees for Canada Program. Nawitka Renewable Resource Consultants Ltd., Victoria, British Columbia). The delivered cost of the chips drops to $83/BDT in this system, or to $55/BDT if development and reforestation costs are not included (Table 3).

The following sections compare these costs with feedstock costs in other regions and examine markets, instruments and policies that could make direct salvage harvest of bioenergy feedstock an attractive option for beetle-killed timber.

9 This is the simple average from a number of case studies on the production of electricity from wood (Wiltsee 2000). Efficiency can be increased through several processes from simple cogeneration through to the more complex gasification, which are covered in the Appendix.

Table 2. Swedish wood pellet budget ($Cdn) for 80,000 tonnes/year

Cost category	$/tonne pellets
Energy	14.94
Labour	8.16
Repair & Maintenance	4.61
Other	0.53
Carrying costs	2.67
Total variable costs	30.91
Total fixed (capital) costs	13.03
Pellet costs pre feedstock	43.94

Source: Hirsmark (2002), converted to $Cdn at 2002 exchange rate.

Table 3. Costs ($/BDT) to harvest and haul lodgepole pine in the Prince George region of British Columbia

	Hauling logs then chipping	Whole-tree chipping on site
Logging costs (tree to truck)[a]	40.71	33.73
Development costs[b]	9.49	7.86
Overhead[c]	16.67	13.82
Basic silviculture[c]	8.57	7.10
Total log costs pre-hauling	75.44	62.50
Hauling[a]	17.16	17.16
Chipping[d]	8.00	8.00
Total delivered, chipped prices	100.61	83.35
Tree to truck + haul + chip	65.88	54.58

Sources: [a] BCMOF 2001, [b] Peter (2004), [c] BCMOF (2004(a)), [d] McNeil Technologies (2003) converted to $Cdn

5. Case studies using beetle-killed pine

It is clear from the previous section that energy prices alone (at the time this analysis was completed) will not support energy production from direct harvest of woody biomass. However, there are likely additional benefits to salvage harvesting at least some of the stands for energy. Leaving large volumes of dead trees on the landscape can increase the risk of fire and can reduce growth of the subsequent stand. The rate of stand growth may be very important to a forest-dependent region, although most of the benefits will be far in the future. As described in Section 3 there are a host of policy tools available to encourage the uptake of renewable energy such as biomass production. We are focusing only on the use of carbon credits in the following analysis. It is recognized that, if used in combination with other incentives, lower credits would be required.

The other benefit to biomass energy production is the value associated with displacing emissions from energy production using fossil fuels. Since biomass releases carbon eventually anyway, its use to generate energy does not add to the long-term total of greenhouse gas emissions. Institutions are under development in certain jurisdictions, such as carbon credits and associated markets, which should help close the gap between current market costs and benefits to carbon-neutral energy production in the future. To illustrate this point, we estimated the level of carbon credit necessary to make bioenergy production feasible with two simple case studies: a) salvage harvest of pine and dedicated direct-fired biomass electrical production in British Columbia, and b) salvage harvest then transport to Alberta and co-firing with coal. Only the net carbon saved (including the system of harvesting, transporting and generating energy from feedstock) versus the reference fossil fuel systems are accounted for in this example. The metric used in this analysis is the payment per net tonne of CO_2 saved by generating electricity from biomass needed to make a decision-maker indifferent between the reference system and the proposed biomass facility. To do this analysis the costs of producing energy from the proposed biomass facility and those of the reference system must be fully accounted for.

Case Study 1 – Direct-fired electrical production from salvage-harvested pine.

The first case is based on direct-fired energy production using feedstock that is harvested solely for energy purposes. The costs for feedstock from the previous section (Table 3) are used in addition to energy production parameters developed from recent studies by the National Renewable Energy Laboratory (Bain *et al.* 2003; Spath and Mann 2000). The costs (pre-feedstock) are modeled here based on the parameters (capital costs and operating costs) given in those studies, although converted to Canadian dollars. The carbon credits that are generated from biomass energy production are based on displacing generation from a natural gas combined-cycle system (the reference system for new generation). The assumed costs for this reference system are those used by BC Hydro in their 2004 Integrated Electricity Plan (BC Hydro 2004(b)) which ranged from $56 to $81 per MWh.[10] The size of the biomass facility that is modelled is 100 MW. It is further assumed that the location of this facility is such that the transport distances are the same as for an average sawmill in the Prince George region, the underlying assumption in the transport costs used in Table 3. The key parameters for the two systems are outlined in Table 4. Other Key Assumptions are that the biomass facility is used for 7884 hours per year, and that wood is converted to energy at 1.398 MWh/BDT

The annualized costs for the biomass plant are approximately $45/MWh prior to the costs of delivered feedstock being included, and rise to $117/MWh using the feedstock costs of $100.61/BDT derived earlier. This is substantially higher than for the reference natural gas system costs. The cost range used by BC Hydro for biomass power production is $56 to $190/MWh (BC Hydro 2004a). Our estimate

10 The levelized costs of NGCC in the BC Hydro analysis formed this range on the basis of size and the assumed future prices for natural gas. The cost estimates were replicated using the BC Hydro assumptions at 250 and 500 MW capacities and the estimated costs are closer to 5 cents kWh^{-1} using a natural gas price of $5.06/MMBtu, a discount rate of 7.5% (real) and the BC Hydro assumed operating and capital costs.

Table 4. Key parameters (per MWh) for case study 1 – direct fired biomass from salvage harvested pine and a new combined cycle natural gas (CCNG) facility

	Biomass 100MW plant	CCNG Reference > 59 MW
Emissions Associated Providing Feedstock (tonnes)	0.027[a]	0.125
Total GHG Emissions (tonnes)	0.027	0.499
Feedstock Costs ($)	75.8	n.a.
Total Generation Costs ($)	123.8	56 to 81

Notes: Any carbon sequestration associated with additional growth due to removing the standing dead pine is not included here.
[a] Based on emissions in Sambo (2002), for the Prince George region, whole tree harvest and haul.

Table 5. Sensitivity analysis on feedstock costs for electrical production and carbon credit values ($/tonne CO_2) to make direct harvest for biomass power generation feasible.

Natural gas prices $/million btu	Feedstock costs in $/BDT				
	0	25	50	75	100
	$ per tonne CO_2 credit				
5	-12.5	25.5	63.3	101.2	139.1
7	-38.8	-0.9	37.0	74.9	112.8
9	-65.1	-27.7	10.7	48.6	86.5
11	-91.4	-53.5	-15.6	22.3	60.2
13	-117.7	-79.8	-41.9	-4.0	33.9
15	-144.0	-106.2	-68.3	-30.3	7.5

Note: Shaded region indicates biomass low cost option.

of $117/MWh coincidentally falls very close to the centre of this range. The value of carbon credits required to lower the biomass system to the $56/MWh to $81/MWh range is $79 to $131 per tonne CO_2. Sensitivity analysis estimating carbon values by varying feedstock costs and natural gas prices are given in Table 5.

As we are modelling costs on the basis of delivering logs to sawmills there may be opportunities to reduce the feedstock costs used for the purposes of bioenergy. There are also other systems to provide feedstock which may have lower delivered costs. This is why we have varied delivered feedstock costs in Table 5 from $0/BDT up to the $100/BDT used previously in this analysis. In addition, there is great uncertainty around future natural gas prices. These are also varied in our sensitivity analysis, changing the costs of the reference system, or opportunity cost of additional electrical generation in BC.

Holding the price of natural gas to $7/MMBtu, feedstock costs of $25/BDT or less result in a cost advantage for the bioenergy facility. The carbon credits in Table 5 are values which equilibrate the cost of production at the bioenergy facility with those in the reference system. Any cell in Table 5 which is shaded indicates a negative carbon credit, and therefore the costs of energy is below that of the reference system. Considering that natural gas prices were $11/MMBtu in the fall of 2005, the bioenergy facility would have a cost advantage if the cost of feedstock were $50/BDT.

Although we have focused on carbon credits as the instrument to narrow the cost gap between biomass and natural gas power generation, as discussed in Section 3, there are a host of instruments that can be used for this purpose including subsidies to collecting or transporting the feedstock or guaranteed price premia for the electricity produced. We are using an estimate unencumbered with respect to these other

programs, but obviously they would result in less carbon credit being required. It is very clear that this option requires financial assistance for any level of feedstock costs above zero unless natural gas prices increase to a level that will make the reference electricity costs much higher.

We limited our sensitivity analysis to changing the costs of the two feedstock sources for both this and the following case studies. As there are underlying assumptions in a modelling exercise such as this, any of them could be tested. Probably the most influential parameter in this model outside of feedstock costs is the efficiency in converting the woody biomass into energy. One means to increase overall energy efficiency is to utilize the process heat along with electricity in a cogeneration plant. This is very common in internal forest industry energy facilities such as those located at pulp mills which can make use of the heat as well as the electricity. Stand-alone plants such as we have modelled here have less opportunity for selling heat in rural BC.

Larger-scale facilities have been also been shown to have increased efficiency in converting wood to energy (Dornburg and Faaij 2001) and exhibit overall economies of scale (Kumar *et al.* 2003. With higher conversion efficiencies the costs that we have estimated would fall..

Case study 2 – Carbon credit values required for feasible transport and co-firing feedstock from salvage-harvested pine.

As discussed in the Appendix, the co-firing of biomass with coal in existing facilities is generally the low-cost option for electrical generation. This is an interesting opportunity for beetle-killed fibre considering the relatively short distance from Prince George to the area west of Edmonton where the bulk of Alberta's coal generating capacity is located (approximately 780 km by road). Alberta has in excess of 5000 MW of capacity in coal-fired electrical plants. At 10% biomass use in co-firing, this would represent greater than 500 MW of wood-fired capacity, nearly equivalent to the total used in the entire province at this time. The second case study is harvesting dead pine, chipping on-site and transporting directly to the coal plants in Alberta where the chips are co-fired with coal to produce electricity. The key parameters necessary for the analysis, and the sources of this data, are given in Table 6.

The incremental costs of displacing coal (per MWh) are the delivered costs associated with three-quarters of a tonne of chips, plus the annualized capital costs of upgrading the plants to accept biomass, less the delivered costs of 0.468 tonnes of coal. The incremental costs of displacing coal with biomass feedstock using the parameters outlined in Table 6 would be $69.18/MWh. Again, as in the previous section, if we examine the costs of CO_2 credits necessary to make this an economically efficient alternative, it would be $71 tonne^{-1} CO_2. Sensitivity analysis is again performed on these results varying the delivered cost of chips and the delivered coal price (Table 7).

The combinations of coal prices and feedstock costs that generate negative values in the table indicate combinations where biomass co-firing lowers the overall generation costs of the electrical facilities. If feedstock can be delivered at $50 per BDT or less, and coal prices achieve $50 per tonne, displacing coal with biomass in these facilities would would be advantageous if carbon credits at were $15 per tonne CO_2 or more. Although these increases in delivered coal prices seem excessive given historic prices, price projections as of 2004 indicate that coal (even relatively low-valued thermal coal) may well achieve $75 per tonne or higher in the next few years (Khani and Shadid 2005).

In order to co-fire biomass on a large scale in Alberta's coal generation sector, feedstock would be needed after the salvage from the beetle outbreak is exhausted. The region in which much of this coal capacity exists also is home to some of the best potential afforestation sites in the country. If contractual arrangements with local private landowners could be initiated to examine the potential to grow fibre for energy, and the costs were not prohibitive, the possibility for co-firing biomass and coal would be increased.

Table 6. Key Parameters for co-firing salvage harvested pine with whole-tree chipping in existing coal generating facilities in Alberta.

	Biomass	Displaced coal
Total greenhouse gas emissions (tonnes/MWh)	0.046[a]	1.02[b]
Feedstock required (BDT/MWh)	0.753	0.468[c]
Delivered feedstock costs ($/MWh)	82.55[d]	15.44[e]
Annualized upgrading costs ($/MWh)	2.08[f]	0

[a] This is the estimate in Table 4 plus emissions associated with fuel use to move chips 780 km to Alberta.

[b] This is the life cycle emissions of coal electrical production from Spath et al. 1999.

[c] The 0.468 coefficient is the average amount of coal used per MWh for US coal-fired electrical generation (EIA 2003).

[d] This is with the whole-tree system, chipped on-site and loaded into chip trucks for delivery in Alberta, thus the $17.16/BDT to move feedstock to a central location from the previous case study is not incurred in this case. The overall transport costs are $44.86/BDT to move the chips to Alberta (derived from Bulk Plus Logistics (2002)).

[e] The price for delivered coal is $33/tonne which is the value used by BCHydro (2004b).

[f] This is the annualized costs of the capital upgrades to existing coal facilities to co-fire with biomass. These are from Bain *et al.* 2003, and the total is $218.60/kW of installed capacity.

Table 7. Sensitivity analysis on carbon credit values ($ tonne^{-1} CO_2) to make direct-harvest beetle-killed pine and cofiring with coal in neighbouring Alberta feasible.

Coal costs $/tonne	Feedstock costs in $/BDT			
	25	50	75	100
	----------$ per tonne CO_2 credit----------			
25	10	29	48	68
50	-2	17	36	56
75	-14	5	24	44
100	-26	-7	12	31

6. Conclusions

Increasing production of biomass, and other forms of renewable energy, is a policy goal that is being pursued by a number of jurisdictions. In fact policy makers, recognizing increased market and non-market costs of fossil fuel energy sources, have pursued a number of both market-based and regulatory approaches to increase the supply of energy from renewable sources. This is most notable in Northern Europe where biomass energy is an important contributor to energy supplies, driven by a combination of renewable portfolio standards, carbon taxes, green certificates and subsidization of capital stock.

The use of wood fibre for energy production in Canada has had little success outside of the forest industry, where a combination of electricity and heat is generated from residual fibre, mostly in pulp mills. In much of Canada, this low-cost residual stream is being fully used, the main exception being in British Columbia where surplus residuals are still available in certain locations. Capacity is increasing to make use of these residuals, most notably to produce wood pellets, which are then exported to northern Europe to take advantage of artificially strong prices in that market.

Increased harvests associated with the mountain pine beelte outbreak are causing much of the surplus in residuals in British Columbia, but it must be noted that this supply stream is temporary and will fall in the next decade as harvests and processing activities are reduced. Firms relying on this residual feedstock will clearly bid up the price as it becomes more scarce, increasing feedstock costs. To further extend supply for biomass feedstock a dedicated harvest for energy purposes will be required. Most jurisdictions in North America have found this a difficult undertaking with the energy prices that prevailed prior to 2005. The US is doing considerable research in this area to find a market for fibre resulting from actions to reduce fire risk.

We used two case studies to examine the potential for using salvage-harvested pine for commercial energy production. The full costs to access, harvest, transport and return a stand to production completely dissipate the delivered fibre value for energy. This is prior to the costs of final conversion being included. Using carbon credit values as the measure to increase uptake it was found that at present energy prices and estimated feedstock costs, carbon credits would have to be in excess of the $35/tonne ($CO_2$) to make either option feasible. It must be noted that the analysis was limited to proven, existing technologies, and new technologies with increased efficiencies may increase the feasibility of this option.

One of the more obvious barriers to biomass energy projects in Canada is the competition from low-cost fossil fuel energy production. In the case of electricity production in British Columbia, these costs are those of natural gas combined cycle reference systems. Likewise, in the case of co-firing with coal, the low delivered costs of coal in Alberta are a serious impediment to using biomass as a feedstock. The spike in natural gas prices seen following hurricane Katrina made biomass generation cost competitive with low-cost feedstock. Following that price spike in the fall and winter of 2005, natural gas prices returned to $5 to $6/mmbtu in the spring of 2006.

An added problem is that standing biomass (especially beetle-killed pine) is spread across a large area, which results in high feedstock procurement and transport costs. In addition, the pay-back period to recover the costs of these facilities is long (20 to 30 years) and beetle-killed feedstock will only be available for perhaps 15 years. It appears unlikely that a new large-scale facility to produce energy from beetle-killed fibre would be feasible without being able to continue operation with another fuel after the 15-year window. If a large-scale project using beetle-killed fibre were initiated, a strategy to phase-in the use of an alternative feedstock would be required. For example, dedicated energy crops such as fast-growing plantation fibre could be used. For our case study of using beetle-killed fibre for co-firing in Alberta coal plants, this would seem to be a logical extension, as a sufficient land base and suitable growing conditions exist for such plantations in Alberta where most of the coal-fired capacity is located. Strategies such as this, that involve using existing facilities with lower capital requirements and shorter pay back periods, offer the greatest potential.

Pre-treatment options such as pelletization offer a lower risk approach to utilizing a temporary source of feedstock such as beetle-killed pine. European regulations and market incentives to utilize pellets favour export of pellets to the northern European market. The rapid expansion of this sector makes it clear that producing pellets from residuals is economically feasible; however, the ability of this sector to absorb feedstocks other than processing residuals is unclear. There are other promising technologies such as fast pyrolysis and the production of ethanol from woody biomass that may also offer opportunities for beetle-killed wood, but the economics of these systems has not been proven.

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Appendix - Energy conversion technologies

This section discusses technologies used to convert woody biomass into thermal and electric (primarily) energy. Although an explanation of the technologies is necessary much detail is omitted as the purpose is to assess the feasibility of using woody biomass to create usable energy. We are interested in the commercial availability of the various technologies, the investment required, the operational costs, and the supply requirements specifically as they relate to the use of woody biomass.

Wood is used traditionally to create thermal energy for space heat, and more recently commercial applications such as electricity or commercial-scale heat to displace other fuels. The biomass-to-energy process consists of four component systems to be assessed within the logistics of getting biomass from the forest to the power generating facility (Hamelinck and Faaij 2002). The first is the ***production*** of biomass, which can be a result of dedicated crops, harvests for forest health reasons, utilization of waste or co-product streams, and salvage harvests following catastrophic fire, insect or disease. The production phase is discussed in the main body of the report. ***Pre-treatment*** includes options for storage, drying processes and ***transport*** medium (logs, bales, chips, pellets). The pre-treatment choice may have implications for feasibility that are discussed further in this section. Finally, the ***conversion*** process is the topic of this section.

It is useful to distinguish between primary and secondary conversion technologies (Roughton 2001). The primary system converts biomass directly into heat or into fuels such as gas or liquid fuels, which are then converted into heat by another, secondary process. Primary conversion technologies, in a broad sense, involve combustion, gasification, or a form of either heat or chemical decomposition. Secondary conversion technologies include boilers, turbines, generators, and external and internal combustion engines.

Given a fuel produced through a primary process, there are a number of technologies that could be used to convert that fuel into usable energy. This analysis considers the potential to produce new fuels to be used in secondary processes. It is the primary technology that has the greatest feasibility implications and therefore that is the primary focus.

Pretreatment

Fuel pellets

Pellet fuel is made mainly of wood waste (sawdust and shavings) that is left over from processing logs into lumber and other wood products. The material is dried, compressed, and formed into small pieces to create a product that is consistent in content, density, size, and quality. Pellets have primarily been manufactured to provide space heating in domestic stoves although an international market is developing, and Canada – including firms in both British Columbia and Nova Scotia – have been exporting pellets to Europe.

Pellets may be a more efficient alternative to transporting logs and harvested residuals of differing sizes and densities. Pelletizing wood fibre increases the density and reduces the moisture content, resulting in a product with greater energy content per unit of volume, thus potentially reducing transport costs. In addition, because pellets are dried, they are less susceptible to decay and insect problems than, for instance, wood chips. Phytosanitary controls on cross border transport may be less of an issue as well with the processed fibre in pellets.

Pellets are a pretreatment option that may be feasible regardless of the conversion technology. However, some conversion technologies may have specific requirements for biomass density and moisture content that would require specific pretreatment. Pellets can be made to order and the typical format is widely usable so pellets could conceivably be used in any of the three conversion technologies discussed in addition to the export and retail markets.

Ethanol

Woody feedstocks, such as those that would result from lodgepole pine killed by mountain pine beetle, are a potential source of sugars (lignocellulosic materials) for ethanol production. Extending the volume of conventional gasoline is an important end use for ethanol, and considerable research has been undertaken to further develop ethanol production processes. Reducing the cost of producing ethanol will be vital in making it a competitive additive in gasoline.

Ethanol can be produced by hydrolysing biomass to produce sugars which are then fermented to produce ethanol. The chemical conversion processes are quite expensive and research is underway to find more economical processes using enzymes to decompose the cellulose into sugars to be fermented. In particular, Iogen, a Canadian company, has initiated construction of a $25 million cellulose-ethanol demonstration plant (Iogen press release, April 2004).

Furthermore, research into using woody biomass with enzymes is being undertaken so that it can replace corn and wheat as a feedstock. At this time, ethanol production is not commercially proven using woody biomass for feedstock. There is considerable interest in ethanol production, as various jurisdictions in the US have endorsed (to varying degrees) the use of ethanol as an additive in gasoline. Ethanol production in the United States grew from 175 million gallons in 1980 to 1.4 billion gallons in 1998, with support from Federal and State ethanol tax subsidies and the mandated use of high-oxygen gasolines. (DiPardo 2002).

A widespread policy requiring ethanol use in North America would ensure a market for ethanol, which would stimulate further investment in research.

Pretreatment Issues

Table A1 is a summary of the pretreatment options for woody biomass feedstock. It is possible that pretreatment of the trees may provide some efficiency gains. Traditionally trees are transported as logs, which have varying degrees of moisture content. Moisture and air content will increase weight and volume, respectively, which will increase transport costs per unit of fibre and so increase the cost of a biomass fuel supply.

Table A1. Pre-treatment options for woody biomass feedstock.

Pre-Treatment	Advantage	Disadvantage	Comments
Logs	• no new technology is required – infrastructure is in place	• may be transportation efficiency gains to increasing density with pre-treatment	• Logs transport costs are the basis for comparison.
Chips	• improved transportation efficiency over logs • mobile technology exists	• losses due to blow-off • decomposition due to moisture content and size - storage problems • phytosanitary concerns	• Do transport efficiency gains outweigh storage and process cost implications? • What are the impacts on existing markets for chips?
Bales	• improved transportation efficiency • mobile technology in use in Europe	• can only be used on branch sized residue	• Given the volumes of beetle-killed trees forest residues are not economical on their own.
Pellets	• technology exists – payback period lower than most technologies • retail and commercial demand • transport, handling and storage efficiencies over logs and chips • increased burning efficiency over less dense fuel results in less fouling, slagging • no phytosanitary concerns	• must be chipped and dried prior to pelleting • must be transported to a pellet production facility as either logs or chips	• Do transport and storage efficiency gains outweigh process cost implications? • What are the impacts on existing markets for pellets?

Conversion

Direct Combustion

Direct combustion can convert a number of fuels into useful energy products. Combustion of biomass is used on a commercial or industrial scale in a Rankine Cycle using steam to generate electricity in a turbine. A Rankine Cycle is a simple power plant consisting of a boiler, turbine, generator, condenser and a pump. Fuel burned in the boiler heats the water to generate steam, which is used to rotate the turbine, which powers the generator.

Recent adoption of combustion technology on a commercial scale has been helped by recognition that disposing of wood residues (typically in "beehive" burners in British Columbia) has costs. First, burning the fuel in beehive burners wastes energy. Secondly, to use beehive burners a firm must pay a waste management fee to the province to emit into the environment. The amount paid would be reduced because combustion for energy production would be more complete and would emit less particulate than beehive burners.

The Williams Lake generating station (Epcor Power L.P.) is the largest example of this type of facility in North America, producing 67-68 MW (net). This facility has five sawmills within 5 km who share the costs of the transport systems and supply the fibre at no cost (Wiltsee 2000). The power generated allows BC Hydro to defer new power projects and, by diverting wood residue from beehive burners, the plant has reduced particulate emissions by over 95%. There is no room for expansion to accommodate fibre from beetle-killed trees as this facility has been operating consistently above capacity (Wiltsee 2000). Little information is available on the costs of producing electricity from this facility, but referring back to Figure 7, BC Hydro estimates a range of costs for biomass energy production of 6 to19 cents kWh^{-1}. Northwest Energy has a long-term contract (25 years) with BC Hydro to deliver at a guaranteed price. Although the price is not public, it was believed to be approximately 6.5 cents/kWh in the late 1990s (Bridges 1997).

Cogeneration

Conventional direct-fired combustion of biomass to create steam is inherently inefficient because it only captures a portion of the fuel's potential energy. The waste occurs in the form of heat as the steam used to turn a turbine is condensed and the remaining heat is allowed to dissipate. Advances in efficient, cost-effective generation technologies have allowed for new systems that combine heat and power production (CHP). These CHP systems, or cogeneration technologies, place the electricity generation equipment first in the system, then use a waste heat recovery boiler to capture the residual heat. The captured heat can then be used to satisfy heating requirements or for creating steam energy, greatly improving fuel use and energy generating efficiencies.

Small-scale cogeneration using forest product residue is becoming more common with sawmills, as the facilities can readily use both the electricity produced and the heat for drying processes. In addition, the biomass residues are centralized and supplied at low costs, and, as discussed previously, environmental management (emission) fees may be reduced or eliminated.

Large-scale cogeneration is more common in the pulp sector. For example, Canfor announced a collaborative project with BC Hydro in late 2003. BC Hydro contributed 49 of the 81 million dollars to build a cogeneration facility at the Prince George Pulp and Paper Mill. In addition, through a load displacement agreement, BC Hydro will pay Canfor a premium for any electricity used internally from this project. This project and others like it are mutually beneficial for the mills and BC Hydro (and they benefit the community in general in terms of avoided pollution). The energy that was previously purchased by the mills can be sold by BC Hydro to new users of energy, thereby displacing the need for new conventional generation facilities. New sources of energy are more and more expensive and might result in more greenhouse gases from fossil fuel as the costs (including environmental costs) of large-scale hydroelectricity are considered excessive. The resulting savings for BC Hydro are passed on, in part, to the cogeneration facility through a load displacement agreement.

The largest biofuel cogeneration plant in the world is situated in Pietsari, Finland and started production in 2001 with a capacity of 240 MW. This plant, known as Alholmens Kraft, runs on a combination of wood wastes, peat and coal, providing power and process steam to the UPM-Kymmene pulp mill and district heat to the municipality of Kymenne (High Technology Finland; 2002.hightechfinland.com/energy-theenvironment/sivu.php?id=metso5&listby= (accessed July 8 2006)).

Co-firing of biomass with coal

Co-firing is the simultaneous combustion of different fuels in the same boiler. Many coal-fired and oil-fired boilers at power stations have been retrofitted to permit multi-fuel flexibility. Co-firing is an option to supplement existing capacity with biomass that has been successfully demonstrated in a full range of coal boiler types and has great potential to increase the uptake of biomass. These systems have the advantage of being able to directly displace some fossil fuel, and yet still use existing plants and existing steam

turbines. If the biomass is in suitable form, it may be possible to add it to the fuel supply of an existing fossil-fuelled plant with minimal changes to the combustion and feed systems. This is the cheapest option presently commercially available (Bain et al. 2003). Costs are much less (up to 90% less) than the capital costs of a new facility like the $81 million cogeneration facility in Prince George.

Co-firing has been successfully demonstrated with substitutions of biomass energy in the range of 10% to 15% of the total energy input with minimal modifications to existing facilities. Kyoto commitments and the requirement to reduce carbon emissions from fossil fuels represent an incentive for coal-fired power plants to use biomass as a substitute for coal. To compete with conventional energy production, especially natural gas, biomass projects need to be large to gain efficiencies in production. As stated previously, co-firing would require a tenth of the capital costs of the other technologies (direct combustion and cogeneration). This advantage is based on the higher cost of building a stand-alone plant over the lower cost of altering an existing facility.

Gasification

Gasification for power production involves the decomposition of biomass in a variety of possible atmospheres (with or without steam, air, or heat) to produce a medium-calorific or low-calorific gas that can be used as a substitute fuel for either gas or diesel turbines. These systems are very efficient in decomposing the biomass into a mixture of liquids, gases and charcoal that can almost all be used, so there is less waste and more energy produced than with typical conversion technologies.

Advanced biomass power systems based on gasification are partly the result of research in coal-based gasification combined cycle (GCC) systems. This technology is not presently considered commercially available although it is considered close and mid-sized plants do exist in Finland, the UK, the Netherlands and the US (Bain et al. 2003). A number of technologies are advancing fast, including hot gas particulate removal, or pyrolysis[11] to produce liquid oil (bio-oil), and production of synthetic gas that could be processed into methanol (Bain et al. 2003; Suurs 2002). In the future, biomass gasification processes will be able to provide hydrogen for fuel-cell or gas-turbine systems.

Research is leading to significant advances in these technologies and concurrent reductions in operating costs, performance improvements, and life extensions that all improve economic efficiencies. These biomass GCC systems are much more efficient than traditional steam cycle systems (BC Hydro 2001; Bain et al. 2003). The ability to convert gas into a liquid may reduce transport costs of the fuel, which may contribute to the feasibility of gasification technologies. The gas produced can also be used as feedstock for chemical processes. In addition, research is underway to develop modular systems to use biomass for small-scale heat and power (USDA 2004), which could reduce the capital requirements enabling (economically) the technology to be situated closer to a supply of fibre.

Table A2 is a general summary of the three broad classes of technologies used to convert biomass to energy.

11 Sometimes called fast or flash pyrolysis

Table A2. Conversion Technologies

Primary Conversion Technology	Advantage	Disadvantage	Feasibility: Comments on Costs and Efficiency (All values are from Bain et al. 2003)
Direct Combustion	• CO_2 neutral and lower greenhouse gases than some fossil fuels • technology is commercially available • cogeneration and retrofits available to improve efficiency	• less efficient which makes small catchment region only feasible option given transport costs – limits feedstock supply • higher net greenhouse gas emissions relative to other biomass technologies • further developments to improve efficiency not yet commercially available (drying, higher performance steam cycle, lower capital cost)	• capital costs = US$160 million – for 100 MW capacity or US$1,605/kW • lower efficiency requires large supply of fuel and local fibre source to reduce transport costs
Co-firing	• retrofits to allow flexibility in feedstock proven reliable – potential lower costs • co-firing facilities may be near enough to areas of beetle-killed pine for economical transport • CO_2 neutral and lower greenhouse gas emissions than coal – Kyoto advantage • wood has lower alkali than some biomass, constraining potentially higher maintenance costs • provincial emission standards may be met without sacrificing production /reduced environmental management fees (emission fees for S, N)	• higher maintenance costs due to slagging, fouling and corrosion from alkali content of biomass relative to coal • coal costs are competitive – transportation and handling costs of biomass are critical	• capital costs = US$16 million – for 105 MW capacity or US$156/kW
Gasification	• double the efficiency of direct combustion (37% vs. 20%) • gas produced can be used for both energy and for chemical processes • smaller scale and transportable models being developed that would allow efficiencies closer to fibre supply • lower CO_2 emissions per MWh relative to other biomass power plants • gasifiers operate at lower temperatures than combustors allowing greater flexibility in feedstock (i.e., they allow for removal of residues that would increase maintenance costs)	• the most efficient technology is not commercially available • commercially available technology highly complex and large scale, therefore very costly	• may be feasible in the future in smaller scale which would reduce capital requirements, improve transport efficiencies • high cost of large scale efficient technology may have a pay back period greater than the MPB fibre supply range • capital costs (BIGCC) US$197 million – for 150 MW capacity or US$1,312/kW

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